

1 FOUNTAIN CONTROL FOR GENERATING DYNAMICALLY CHANGING
2 FLOW PATTERNS

3
4 BACKGROUND OF THE INVENTION

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6 This invention relates to water fountains and an associated programmable
7 controller for generating dynamically changing flow patterns.

8 Current indoor water fountains especially those intended for tabletop use
9 generally have a preset flow rate and one or more outlets to channel water over
10 the fountain elements. These fountains are non-dynamic and have a fixed flow
11 pattern.

12 Virtually all indoor fountains employ a low power alternating current
13 submersible pump. These pumps are generally comprised of a single-phase
14 permanent-magnet synchronous motor (PMSM) with a multi-pole permanent-
15 magnet rotor and a coupled impeller. Such pumps normally have no directional
16 preference and are characterized by having notoriously low start-up torque. In
17 order to overcome the low start-up torque problem and attain a pump with
18 reliable starting characteristics, impellers have been designed with flexible blades
19 and with mechanical slip-clutch arrangements to allow the rotor to begin rotation
20 without having to overcome the water resistance of the impeller. These slip-
21 clutch arrangements allow the impeller to rotate freely for a portion of one
22 revolution before engaging a stop that prevents further rotation of the impeller
23 relative to the rotor. Even with these modifications the majority of such pumps do
24 not reliably start which is unfortunate in a fountain application. Pump and impeller
25 apparatus with the above characteristics have been taught by Cabalcante
26 (US4247265), Ellis, et al (US 5282961) and Willinger and Ivasauskas

BRIEF SUMMARY OF THE INVENTION

It is a primary objective of this invention to provide a programmable controller for varying the flow rate of the fountain in a predetermined manner by varying the flow rate of a pump so as to generate dynamically changing flow patterns.

It is a related object of this invention to provide a variation in the flow rate of water to a fountain element by simultaneously changing the frequency and pulse width of an alternating current (AC) input to an alternating current permanent-magnet synchronous motor pump in such a manner that the motor's power requirements are met over as wide a speed range as possible.

It is a related object of this invention to provide a programmable fountain pump control for generating a predetermined multiplicity of sequential flow volumes to a fountain so as to generate changeable water flow patterns over time.

It is a related object of this invention to provide a programmable pump control coupled with a rigidly connected rotor and impeller assembly that will repeatably and reliably start and will operate without impeller chatter.

It is a related object of this invention to provide a microprocessor driven control to vary the output of a low voltage AC PMSM in a predetermined manner.

It is a related object of this invention to provide a pump control that varies pump output in response to changes in the ambient sound level, to changes in an external audio signal and to changes in an external data input/output signal.

These and other objects of the invention are met by a programmable fountain controller for varying the flow rate of a fountain pump in a predetermined manner, wherein the mode of operation is selected from a group comprising a programmed mode, an audio input mode, a manual mode and an external data input/output mode.

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1 FIG. 3 shows a flow chart of a program for the micro-controller shown in
2 FIG. 2. The program essentially comprises a repeated loop (305) which switches
3 the output waveforms from one state to the next (390) to generate the output
4 pulsed waveform which powers pump 130. The timing of this output state
5 switching is the essential purpose of loop 305 and its associated sub-routine
6 timings.

7 FIG.4 shows a graphical output state diagram for one pulse cycle for the
8 case of differential drive. As shown, there are two outputs, Output 1 (400)
9 (labeled "A") and Output 2 (410) (labeled "B") wherein Output 2 is the inverse of
10 Output 1. States 1 and 3 (440, 444) are the "dead time" states with duration
11 equal to t_1 (420). In state 1 and state 3 the output pulses are set such that zero
12 volts appears across the pump motor. States 2 and 4 (442, 446) are the "pulse
13 states" having duration equal to t_2 (430). In state 2 and state 4 the voltage
14 appearing across the motor is approximately equal to $+V_{sup}$ and $-V_{sup}$,
15 respectively. Thus the three voltage levels appearing across the pump motor are
16 $+V_{sup}$, $-V_{sup}$ and zero. These are switched for Output 1 and Output 2 in program
17 block 390) of FIG. 3.

18 Alternatively for some applications a single output, Output 1, may be
19 switched in a similar manner. In such a case the required DC supply voltage
20 (V_{sup}) would be approximately double that of the differential output version
21 depicted in FIG. 4.

22 The required output state timing (block 370 in FIG. 3) is calculated such
23 that the repetition rate frequency $\{f = 1/(2x(t_1 + t_2))\}$ of the output pulse
24 waveform and the pulse width t_2 (430) of the voltage waveform feeding pump 130
25 is optimally determined for a given desired pump flow rate. Programmatically, this
26 information is derived 1) arithmetically or 2) from "look up" tables incorporated
27 into the internal micro-controller program or from both and is determined in such
28 a manner as to provide a waveform with characteristics most suitable for pump

drive within acceptable pre-determined maximum and minimum flow rates that avoid stalling. To this effect, determination of the required flow rate may be a function of any combination of audio or external signal level, potentiometer settings, switch setting and instruction sequence reads.

The program in FIG. 3 shall now be described.

Initialize and Set Defaults block 306 initializes the micro-controller and sets initial default settings for generating a start-up pump flow rate. Timers Reset block 310 resets the timers to zero. Output Pulse Reset block 320 resets Output 1 and Output 2 to zero (states 1 and 3 in FIG. 4).

Read Mode Switch block 330 then reads mode switch 235 to determine program mode; this may set other parametric values depending on the switch setting. A sequence of decision blocks are then executed for each of the switch modes described previously. These are Audio Input Mode decision block 340, Manual Flow Setting Mode decision block 350, External Data I/O Mode decision block 355 and Programmed Flow-Variation Mode decision block 360. Depending on whether the result of each of these blocks is "yes" or "no", various program functions (345, 352, 358, 365) are performed as shown in FIG.3. Note that the flow chart allows the potential for a given mode to influence modes further down in the sequential chain.

Next, Calculate Pulse Width & Frequency block 370 calculates the desired frequency and pulse width values for t_1 and t_2 for the next cycle based on the results of the above decision blocks and subsequent operations. Test Timers block 380 then initiates a programmed wait t_1 until the time for the next state change for Outputs 1 and 2. When this expires, the Switch Pulse States block 390 switches Outputs 1 and 2 to their next respective states. Test Timers block 395 then initiates a second programmed wait t_2 . After this wait expires, the program returns to Timers Reset block 310 to close the loop (305).

1 The impeller and rotor of pump 130 for use in conjunction with controller
2 150 in FIG. 1 shall now be discussed. In order for pump 130 to operate without
3 noise and chatter when driven by controller 150, rigid coupling of the rotor and
4 impeller is required. This is a consequence of the pulsed nature of the input to
5 the pump supplied by switching circuit 240 in FIG. 2. If commonly used slip-clutch
6 arrangements were alternatively specified, which would allow the impeller to
7 rotate freely for a portion of one revolution before engaging, chatter and noise
8 would ensue; this would be exacerbated under conditions of variable pump back-
9 pressure.

10 Aside from eliminating chatter and impeller noise, an allied benefit of the
11 rigid rotor/impeller assembly when used in a PMSM pump coupled with controller
12 150 is that starting problems that are a major concern with PMSM pumps of the
13 type used in aquariums and small fountains are completely eliminated.

14 It should be noted specifying a rigid coupling of the impeller and rotor is in
15 direct opposition to the slip-type couplings commonly used with PMSM pumps to
16 reduce starting problems when such pumps are operated with AC power from the
17 mains or from step-down transformers. In fact, simple PMSM submersible pumps
18 for aquarium and/or fountain use would not start when powered by conventional
19 AC line sources if they employed the fixed rotor and impeller assembly of this
20 invention.

21 FIG. 5 shows a side view of a first embodiment of a rotor and impeller
22 assembly for PMSM pump 130 according to this invention. The assembly is
23 comprised of rotor 510, rotor shaft 504, coupling 503, impeller shaft 502 and
24 impeller 500 with plurality of evenly spaced impeller blades 505. Impeller 500,
25 shafts 502 and 504, coupling 503 and magnetic rotor 510 are concentric with one
26 another. Impeller shaft 502 is press-fit into impeller 500 allowing no relative
27 motion. Similarly, rotor shaft 504 is press-fit into rotor 510 allowing no relative
28 motion. Coupling 503 rigidly couples shafts 502 and 504 without allowing their

1 relative rotation. Cylindrical opening 520 in rotor body 510 is provided to freely
2 receive a fixed shaft in pump 130 (not shown) for constraining side-to-side
3 motion and wobble of the impeller assembly when it rotates in the pump motor's
4 magnetic field.

5 FIG. 6 shows a side elevation view of a second embodiment of a rigid
6 rotor/impeller assembly for use with controller 150. In this embodiment shaft 620
7 is press-fit into rotor 610 and impeller 600 so as to preclude relative rotation of
8 600 and 630. As in the first embodiment of FIG. 5, a cylindrical opening 630 in
9 rotor body 610 is provided to freely receive a fixed shaft in pump 130 (not shown)
10 for constraining side-to-side motion and wobble of the impeller assembly when it
11 rotates in the pump motor's magnetic field.

12 Various modifications of the disclosed invention can be considered without
13 deviating from its scope. As one modification, a multiplicity of pumps can be
14 controlled by a single micro-controller 200. This would allow synchronization of
15 multiple pumps either by programmed mode or by combinations of audio input,
16 external data I/O (i.e. DMX 512 format) and programmed mode. In this instance
17 a microprocessor with the appropriate number of I/O ports and sufficient
18 programmed memory would be chosen based on program requirements and the
19 number of pumps to synchronize.

20 As another modification, a multiplicity of pumps could be controlled by
21 multiple similar micro-controller circuits such as described above with each
22 device communicating or synchronizing operation through a digital
23 communication mechanism.

24 As another modification, other switches may also be provided either as
25 replacement for or in addition to potentiometer 270 to allow the micro-controller
26 to determine other operational parameters based on user input.

27 As another modification, a unit similar in operational principle to that
28 described except working directly off of line voltage (no wall transformer) and

1 driving a high voltage (e.g. 110 volts AC) pump can be realized. The potential
2 drawback of this modification would be the potentially lethal voltages generated
3 by the circuitry.

4 As another modification, while four impeller blades are shown in FIG. 5
5 and FIG. 6, alternative numbers of blades may alternatively be specified to
6 optimize the operating characteristics of a particular pump.

7 Although there has been shown and described hereinabove a specific
8 arrangement of a fountain and control for generating dynamically changing flow
9 patterns in accordance with the invention for the purpose or illustrating the
10 manner in which the invention may be used to advantage, it will be appreciated
11 that the invention is not limited thereto. Accordingly, any and all modifications,
12 variations, or equivalent arrangements that may occur to those skilled in the art
13 should be considered to be within the scope of the invention as defined in the
14 annexed claims.